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Empirically modeling carbon fluxes over the northern Great Plains grasslands

Li Zhang[1], Bruce Wylie[1], Lei Ji[1], Tagir Gilmanov[2], and Larry L. Tieszen[3]
[1]SAIC, contractor to U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS), Sioux Falls, SD, USA. lizhang@usgs.gov. Work performed under USGS contract 03CRCN0001.
[2]South Dakota State University, Brookings, SD 57007, USA
[3]USGS/EROS, Sioux Falls, SD 57198, USA

1. Introduction

The grassland ecosystem in the U.S. Great Plains occupies about 1.5 million km^2. However, the contribution of the grasslands to local and regional carbon budgets remains uncertain due to the lack of carbon flux data for the expansive grassland ecosystems under various land managements, land uses, and climate variability. An understanding of carbon fluxes across the ecosystem is essential for developing carbon budget models at regional, national, and global scales.

2. Methods and Materials

A remote sensing-based empirical model, piecewise regression (PWR) model (Wylie et al, 2007; Zhang et al., 2007), was modified in this study to estimate the grassland carbon fluxes in the northern Great Plains. The model integrates spatial database and extended the data collected from six grassland flux towers to the entire grassland ecosystem. We used this model to estimate the spatio-temporal carbon fluxes across the study area by exploring the empirical relationship between environmental variables and tower-based measurements. Net ecosystem exchange (NEE) between land and atmosphere were measured using eddy covariance and Bowen-Ratio techniques. We partitioned 30-minute CO_2 fluxes into total ecosystem respiration and gross primary production (GPP) using the light response curve analysis (Gilmanov et al., 2005). The predictors include the 8-day composite MODIS normalized difference vegetation index (NDVI) at 500-m resolution, precipitation, temperature, photosynthetic active radiation, and phenological metrics. We also incorporated the actual vegetation evapotranspiration data derived from a Vegetation Evapotranspiration (VegET) model (Senay and Henebry, 2007), which takes into account soil moisture and land surface phenology. Cross-validation by sites and years showed that the improved PWR model increases the estimation accuracies over the previous PWR model and reflects the variations in water stress that may not be monitored by vegetation indices alone because of the lag-response of vegetation indices to water deficits. Based on model simulations, we mapped the 8-day intervals and 500-m resolution carbon fluxes for 2000–2006 in the northern Great Plains grasslands.

7. Conclusions

- The CO_2 exchanges over the northern Great Plains grasslands are highly variable in space and time.
- NEE in the study area was consistently low and fluctuated around zero. On average for the 7 years, the study area was a marginal carbon sink.
- The annual NEE transits from sinks to sources in the dry years of 2002, 2004, and 2006. If drought events increase in the future, the ecosystems may change to larger carbon sources.

8. Future plans

- Assess and monitor the regional and temporal trends of carbon fluxes and determine important transitions and environmental drivers of carbon sink/source in this region.
- Interpret the climate and management impacts on grassland ecosystems.
- Extend this model method to other ecosystems (crop, tallgrass, and mixed prairie) and ecoregions.
- Compare the PWR model with other carbon models.

References

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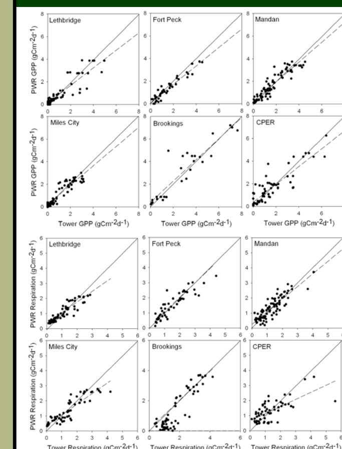
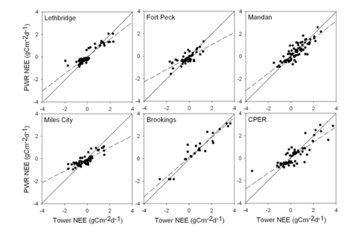
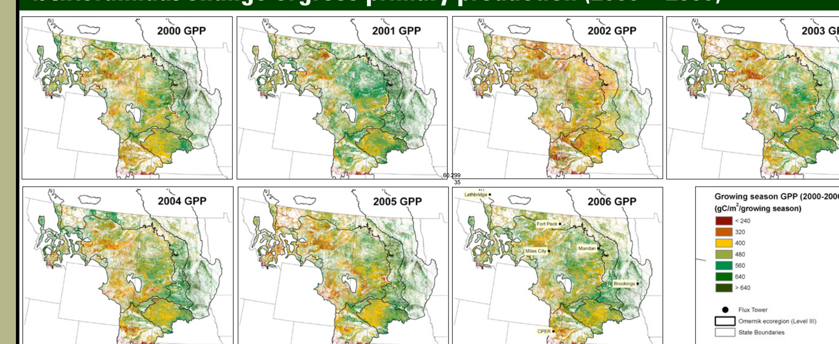
3. Cross-validation by withholding site and year



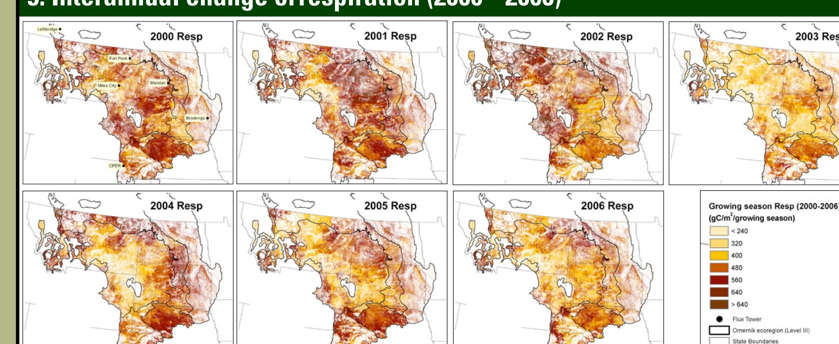


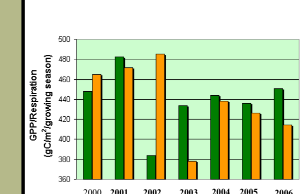
The results showed a good agreement between PWR-estimated and tower-measured fluxes by withholding site and year. Cross-validation indicated the robustness of the PWR model for estimating regional grassland carbon fluxes in the northern Great Plains. The results show $R^2 = 0.77$-0.92 for GPP, $R^2 = 0.58$-0.90 for NEE, $R^2 = 0.49$-0.92 for respiration by withholding site and $R^2 = 0.77$-0.85 for GPP, $R^2 = 0.46$-0.90 for NEE, $R^2 = 0.62$-0.92 for respiration by withholding year.

4. Interannual change of gross primary production (2000 – 2006)



5. Interannual change of respiration (2000 – 2006)





GPP was relatively stable with the greatest production of 482 gC/m^2/growing season in the wet year 2001 and the lowest production of 384 gC/m^2/growing season in the dry year 2002.

We estimated a 20 percent reduction of GPP in the dry year 2002 compared to the wet year 2001, which resulted in an anomalous net source of carbon dioxide (–19 gC/m^2/year) to the atmosphere. Ecosystem respiration reached the maximum value of 485 gC/m^2/growing season in the dry year 2002.

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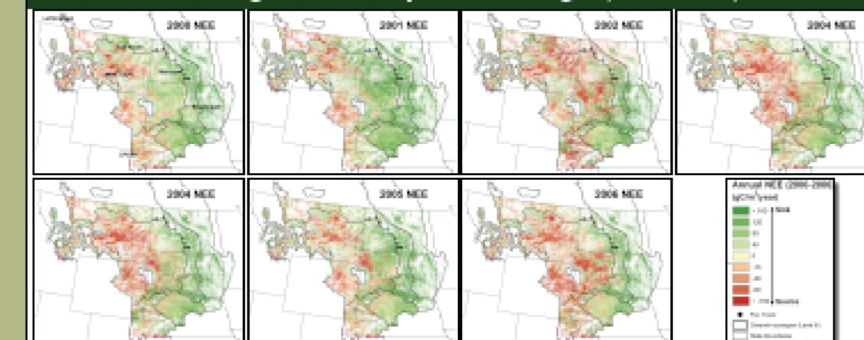
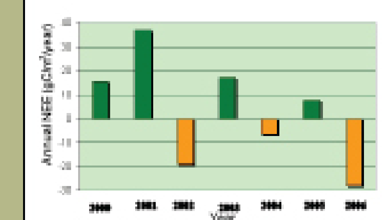
6. Interannual change of net ecosystem exchanges (2000 – 2006)





The northern Great Plains grassland NEE is strongly influenced by the distribution of annual precipitation.

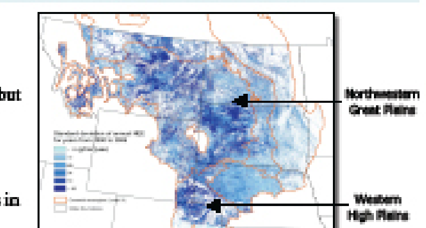
Specifically, the NEE map shows extensive carbon sources in drier western regions and carbon sinks in wetter eastern and southern regions, which was in line with the east-west gradient of annual precipitation across this region.

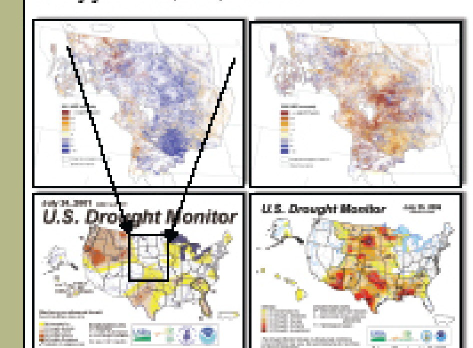
The annual NEE varied among years from –28 gC/m^2/year (source) in 2006 to 37 gC/m^2/year (sink) in 2001, with sources in 2002, 2004, and 2006, and sinks in other years.

The standard deviation map of the 7 years of annual NEE indicated that annual NEE has the largest variance in the Northwestern Great Plains and the Western High Plains, but it is relativity stable in other ecoregions.

We calculated the NEE anomaly (the difference between annual NEE and mean of 7 years of NEE) for each year.

The anomaly maps (2000 – 2006) showed large anomalies in the dry years 2002, 2004, and 2006.



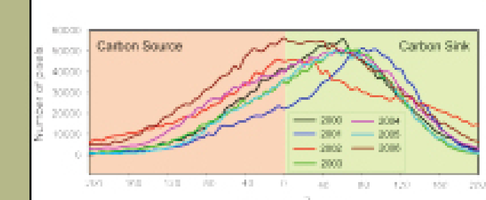


The interannual variability in NEE is significantly related to drought with carbon sources in the drier years of 2002, 2004, and 2006.

In the wet year 2001 (indicated by the drought monitor map from National Drought Mitigation Center, http://drought.unl.edu/dm/monitor.html), NEE was above the average annual NEE over a large spatial extent in this region with carbon sinks.

In the drought year 2006, NEE was below the average annual NEE over the entire region with carbon sources.

The carbon budgets depend, to a great extent, upon the precipitation and its distributions in this region.



Left graphic shows the total number of pixels in this region for the dynamic range of annual NEE.

For the years 2000, 2001, 2003, and 2005, the histogram peaks locate in the carbon sink area.

However, in 2006 and 2002, the histogram peaks move toward the carbon source area. For years 2002, 2004, and 2006, a second peak appears around source area over the range from –40 to –60 gC/m^2/year